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"The Current Status of Deep Ocean Water Applications:
Meeting the Okamura-Craven Challenge"

By John P. Craven, Common Heritage Corporation
and
Thomas H. Daniel, Natural Energy Laboratory of Hawaii Authority

Shortly before he died, Japan's ocean technology ambassador Kenji Okamura met with John Craven to discuss how to generate the political and fiscal environment needed to establish a project that would demonstrate self-sufficiency in energy, fuel, fresh water and protein for an oceanic coastal community. The reasoning behind this request came from their mutual recognition that the world population was outgrowing world resources at an exponential rate and that the population growth was accompanied by a mass migration to the coastal zone, where the natural resources of the ocean and its continental shelves seemed to provide immediate relief.

Unfortunately the pressure on resources resulting from this movement to the coast magnifies the pressure that comes from the absolute increase in population. This pressure is further aggravated by the fact that nutritional requirements of the human double at age fourteen and that the bulk of the world population growth is in the bracket from birth to teens.

It was Kenji Okamura's thought that the demonstration of environmentally sustainable self-sufficiency, supported by the U.S. or Japan in one of these islands, would highlight the possibilities and pave the way for aid programs throughout the world.

In tribute to his forward thinking and following his untimely death, Craven decided that the most appropriate response to Okamura's last request would be the establishment of the Okamura - Craven challenge. This challenge, addressed to all of the ocean development communities of the world, was presented to the UJNR Marine facilities panel at its 1997 meeting. It is as follows:

> "Each oceanic community that wishes to participate in this challenge shall identify a coastal community to be developed such that it achieves self-sufficiency in energy, fuel, fresh water and protein. A plan and a schedule for its implementation should then be identified and the work should commence."

We report here on the extent to which this challenge is being met today, by summarizing the status of development in the areas of OTEC, Aquaculture, chilled-soil agriculture, deep water air-conditioning and other applications.

OTEC

The big news about OTEC is the development of the Kalina and Uehara cycles which use an ammonia water mixture to provide significantly higher energy efficiency at OTEC temperatures than the standard Rankine cycle.

Professor Uehara and his Saga University team designed the 1 MW plant that NIOT attempted to deploy of Tamil Nadu last March. Thought the cold water pipe was lost during the deployment, the OTEC plant remains operational and NIOT is preparing to re-deploy in early 2002. Saga University and Satomi Industries have also negotiated an agreement with the government of the Republic of Palau to develop OTEC for that island nation.

The Natural Energy Laboratory of Hawaii Authority (NELHA) is deploying new 140 cm diameter surface and deep seawater pipelines that were originally designed in 1989 for a 1 MW OTEC plant. The 915 m intake depth of the deep seawater pipeline will provide 4C water, yielding a minimum ÄT of ~20C. A recent design by Exergy, Inc. of Hayward, CA USA, working with Ocean Energy Systems of Honolulu, indicates that a Kalina cycle plant can produce about 1.4 MW from the same seawater system. NELHA has not yet been successful in negotiating a satisfactory contract for installation of that plant, but efforts continue to develop an OTEC system using the new pipelines.

AQUACULTURE USING DEEP OCEAN WATER

Aquaculture represents the primary use of deep ocean water today. The demand for aquacultural products is increasing, and the inherently smaller seawater requirements compared to OTEC make aquaculture enterprises more realizable with present pipeline technology. As noted many times previously, deep ocean water has three primary characteristics that make it especially useful for aquaculture: it's cold, it's clean and it's nutrient rich. The low temperature makes it possible to grow plants and animals (such as *nori* and Maine lobster) that don't normally grow in the tropics, but the primary value of the coldness comes from the temperature control that can be achieved by mixing with warm surface water. The low pathogen levels and high nutrient levels are both useful characteristics of the deep water for aquaculture, but neither is as important commercially as is ability to control temperature at low cost.

The Japanese government, led by Takayoshi Toyota and Dr. Toshimitsu Nakashima of JAMSTEC, has installed several deep ocean water pipelines, primarily for aquaculture research and development.[1] The initial 10-cm diameter pipeline, installed to 370-m depth at the Kochi Artificial Upwelling Laboratory (KAUL) at Cape Muroto in Kochi Prefecture in 1989, provided such encouraging results that a second identical pipeline was installed at KAUL in 1995. The positive results at KAUL, and the discovery of cold water near shore at 100 m depth, also led the government of Toyama Prefecture on the Sea of Japan to install their own pipeline, which was followed shortly thereafter by another pipeline installed by the City of Nyûzen in Toyama. Former Governor Masahide

Ota of Okinawa was so impressed with the potential of deep ocean water when he visited NELHA in 1995, that he decided to construct a similar facility in Okinawa. The prefecture selected a site on Kume Island about 100 km offshore of Naha on Okinawa. The Okinawa Deep seawater facility began pumping deep seawater ashore in June 2000 through two 28-cm diameter pipelines extending to 600 m depth. A large research and development facility has been constructed at the site where the pipelines come ashore. Primary intended uses are for agriculture (see below) and aquaculture research and development.

Citizens of Muroto City near KAUL were allowed to use the deep seawater following its use by the R&D laboratory, and local businessmen have developed a large number of commercially successful products from the water. The primary product is desalinated deep seawater, which is sold as bottled drinking water at prices greater than 400¥/liter. A large public relations campaign has created significant demand for this product, though we have seen no verifiable scientific evidence that the water is chemically different from any other pure water. Many other beverage and cosmetic products developed from the deep seawater are also selling well in Japan. The success of these initial products led the City of Muroto to install a new 28-cm diameter pipeline that provides DOW to the Kochi Prefectural Deep Seawater Laboratory and Aqua Farm about 1 km away from KAUL. Pressure from local politicians and businessmen also led JAMSTEC and the Science and Technology Agency (STA), which funds the activities, to relinquish the KAUL facility and its two deep seawater pipelines to the Kochi Prefectural government, which sells the seawater to producers of commercial DOW products. Several companies from Japan have begun research and commercial projects at NELHA for the production of deep seawater products, including desalinated water and sea salt.

JAMSTEC and STA are now developing a new research facility at Yaidzu in Shizuoka Prefecture that will allow continuation of the research (mostly upwelling aquaculture) begun at KAUL. The new laboratory will be served by two 28-cm pipelines, one extending to 700 m depth and the other to 350 m.

In Hawaii, NELHA continues to expand its aquaculture commercialization activities.

- Cyanotech Corporation, which has been producing microalgae at NELHA since 1984, is once again expanding production, following several years of recovering from the 1997 termination of its exports to China. The company is developing markets for its new astaxanthin neutraceutical products while continuing large scale production of its established line of spirulina health food supplements.
- Aquasearch, Inc. continues to expand sales of its astaxanthin products which are also being promoted in the neutraceutical market.
- Kona Cold Lobster Co. has developed technology for growing Maine lobster (*Homarus americanus)* from eggs to adults using suitable mixtures of NELHA's surface and deep seawater. Since the natural catch of these delicious lobster has remained high (and the price, therefore, low) the company continues to re-sell adult lobster flown in from the U.S. East Coast.
- Royal Hawaiian Sea Farms also continues to grow its business of selling various "edible sea vegetable" products, throughout Hawaii.

- Uwajima Fisheries, Inc. also grows *ogo* and other sea vegetables to supplement its main business of producing high quality *hirame* (flounder) for Hawaii's sushi market.
- Kona Bay Marine Resources has progressed from its initial polyculture of oyster and shrimp to production of clams for export to asian markets.
- Ocean Rider, Inc., which is just expanding to a new 1 acre (.4 ha) incubator facility in NELHA's commercial area, grows seahorses for the aquarium trade and might eventually also supply the Chinese market for dried seahorses, which supposedly do everything from enhancing sexual performance to fighting heart disease.
- Black Pearls, Inc. is now capitalizing on several years of research on culturing black-lipped oysters by developing commercial pearl farms in the Marshall Islands and Hawaii.

Several new companies are productively occupying the area initially developed by former tenant, Ocean Farms of Hawaii, which ceased operation in 1993.

- Taylor Shellfish brings oyster and clam "spat" (up to 1 mm size) from their farms in the U.S. Pacific northwest to grow rapicly in NELHA's year-round sunshine and nutrient-rich seawater. The animals are returned to their Washington and Oregon homes after 2-3 months when they reach 1-2 cm size.
- Coast Seafoods, another U.S. Pacific Northwest company, also uses NELHA's water and sunshine to promote growth of juvenile oysters and clams.
- High Health Aquaculture, Inc. produces guaranteed "specific pathogen free" (SPF) shrimp, used throughout the world as broodstock for shrimp farming operations.
- Indo-Pacific Sea Farms produces a wide variety of marine aquarium animals and foods, which are widely distributed over the internet.
- Pacific Harvest, Inc. grows *moi* (pacific threadfin, *Polydactylus sexfilis*) a local Hawaiian fish delicacy which, though depleted in the wild, is becoming very popular in local restaurants. That company has found that dipping these fish in cold deep ocean water kills them so quickly that their flavor is significantly better than those killed by other means.

Big Island Abalone Corporation (BIAC), the fastest growing company at NELHA, is just completing expansion into the initial 4 ha of a 202 ha site in the HOST Park area of NELHA. Their primary initial products are Ezo (Japanese Northern), and Red (California) abalone. BIAC will be the major initial user of the deep and surface seawater that will be pumped ashore through NELHA's new 140-cm seawater system.

Several other companies are just beginning to develop aquaculture businesses at NELHA, for example:

- Moana Technologies, Inc. is beginning pre-commercial research on development of marine shrimp broodstock.
- Marine BioProducts International has completed its research on specialty agar production and is preparing to establish a commercial algal growout facility at NELHA to supply its raw materials.

AGRICULTURE

As noted above, Okinawa Prefecture developed its deep ocean water facility on Kume Island primarily to exploit the capability of producing temperate crops year-round in a tropical climate. The potential of this capability is demonstrated by Spinach, an important element in the Okinawan diet. Spinach does not grow well in the warm Okinawan summers, so the market price in summer is about ten times that in the cooler winter months when the product grows well. Initial calculations indicated that using deep cold water to promote large production of spinach in summer would provide sufficient revenues to defray the costs of the whole project. Research on various agricultural products is now beginning at the Kume facility.

The Common Heritage Corporation has been producing a wide variety of agricultural crops at its NELHA facility for many years. More than 150 different crops have been grown, almost all showing improved growth characteristics compared to other sites. Some exciting examples include: strawberries, tomatoes, corn, cotton, squashes, grapes, orchids, etc. Recent experiments indicate that temperate grasses, important as turf for golf, soccer, football and other sports events, grow well in chilled soil with warm tropical air temperatures. There appears to be a very large market for these various forms of "eco-turf".

AIR CONDITIONING

Since 1990, NELHA has used off the shelf titanium heat exchangers to cool the chill water that air-conditions its main laboratory buildings. This system saves the facility nearly $4000 per month in electricity cost, since there is no need for the chiller which is the primary energy consumer for conventional air-conditioning systems.

Makai Ocean Engineering, Inc. (MOE) of Waimanalo, Hawaii, the design engineers for NELHA's pipeline systems, have promoted the idea of deep ocean water air conditioning for many years.[2] They have worked with groups from Curacao, Fiji, Guam, Haiti and many other tropical sites toward the development of practical resort air-conditioning with deep seawater. The financial payback period for such systems can be as short as five years, but none have yet been built.

As a result of their work promoting deep seawater pipelines for air-conditioning, MOE was hired to participate in Cornell University's Lake Source Cooling (LSC) project.[3] They designed a 3.2-km long, 160-cm diameter high density polyethylene pipeline that extends to almost 100-m depth in Cayuga Lake near the Cornell campus. The pipeline, installed in the fall of 1999, began providing cold water to cool the campus in the summer of 2000. The system provides 20,000 tons (88 MW) of air conditioning and a reduction of more than 33,000 tonnes per year of carbon dioxide released into the atmosphere. It now serves as a model of potential savings for new developments in the tropics.

NELHA's NEW SEAWATER PIPELINE SYSTEM

As noted above, the Natural Energy Laboratory of Hawaii Authority is currently installing a new seawater supply system to serve the Hawaii Ocean Science and Technology (HOST) Park. The pipelines come ashore through shore-crossing tunnels extending from 150 m offshore at 24 m depth to a 10 m deep sump 150 m onshore. The 140-cm deep seawater pipeline will provide up to 1.70 m^3/sec of 4°C seawater from an intake at 915-m depth. The 140-cm diameter surface seawater intake is attached to the 24-m deep offshore end of its shore-crossing tunnel.

The current installation contract has three major components:

1) Installation of the deep seawater pipeline is the largest and most risky part of the project. The 2.80-km long high density polyethylene pipeline was assembled, with all of its 1,045 tonnes of concrete anchors attached, at Kawaihae Harbor, 40 km north of NELHA. It was towed in the ocean to the deployment site off NELHA"s Keahole Point facility on the night of 6 October 2001. The initial deployment on the night of 7 October was aborted shortly after flooding had begun from the nearshore end, when one of the two 10.5-cm diameter nylon ("sampson braid") lines holding the offshore end of the pipe parted. Nearly 30 of the nearshore anchors were already on the bottom, so air was immediately pumped back into the pipe from the barge at the offshore end, re-floating the pipe so that it could be secured on the surface. Replacement nylon braid lines were procured from Houston and flown in late on 10 October, allowing re-assembly of the system on 11 October. The pipeline was deployed successfully overnight on 11 October, with the bottom anchor touching down about 8 am on 12 October. Strong currents during the deployment prevented divers from removing the blind flange at the offshore end, so a remotely operated vehicle is attempting to remove that flange as this is written on 14 October. Otherwise, the deployment was very successful. A spool piece will now be fabricated and installed by divers spanning the 14-m distance from the nearshore end of the pipe to the shore crossing tunnel.
2) The nearshore warm water intake will minimize fish entrainment via a velocity cap that will prevent vertical flows and a fiberglass reinforced plastic (FRP) grating structure with sufficient surface area to keep horizontal flow velocity below 30 cm/s. The intake structure will be installed immediately at the end of the shore crossing tunnel at 24-m depth.
3) The onshore pump station will be installed in the sump located at the onshore end of the tunnels, 150 m from the ocean. Each pump will be at the bottom of a 12.2-m high by 1.5-m diameter FRP canister. Three of these canisters will be grouped around each of two 10-ft diameter FRP cylinders, one flanged to the end of each shore crossing tunnel to serve as intake sumps for the surface and deep seawater.

The pumps in this primary system will pull water through the two intake pipes and deliver it to booster pumps that will pump it to needed elevations in the HOST Park. The installation of this warm and cold seawater distribution system will be performed under a separate contract to be issued in the first quarter of 2002. Seawater pumping to customers in HOST Park is scheduled to begin from this new system in July of 2002.

The $21+ million cost of this system is being funded as a Capital Improvement Project by the State of Hawaii. The State intends that the new businesses developed around the water pumped through these pipelines will help to diversify Hawaii's economy and make it less dependent on tourism.

CONCLUSION

Though no single entity has clearly met the Okumura-Craven challenge outlined in our introduction, the collective progress summarized herein has moved us far along the path toward the future that Kenji Okumura envisioned. It is clear that deep seawater provides tremendous potential for the near-term development of environmentally sustainable, self sufficient coastal communities.

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[1] Takuma Nakasone* and Sadamitsu Akeda, "The Application of Deep Sea Water in Japan", UJNR Technical Report No. 28, 2000, p. 69-75.

[2] Van Ryzin, J. and T. Leraand, "Air Conditioning with Deep Seawater:A Cost-Effective Alternative," Sea Technology, 33(8), September 1992, p.37-40.
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[3] Saulnier Beth. 1997. One Cool Idea, Cornell Magazine, Nov-Dec 1997, Ithaca, NY USA, p.34–41 and Holmes Liz. 1999. In the Drink: Cities Try Cooling Off with Deep Lake Water. Scientific American, Oct. 99, p. 47-8. (http://www.sciam.com/1999/1099issue/1099techbus2.html).